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PRESSURE TESTING RESULTS (AS A DECISION TOOL FOR DECIDING LOW OXYGEN OR ULTRA-LOW OXYGEN OR HIGH OXYGEN STORAGE) OF SEMI-HERMETICALLY SEALED CONTROLLED ATMOSPHERE STORAGE INSULATED CHAMBERS

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ABSTRACT

Controlled atmosphere storage technology is used widely for storing apples for long term. The very basic need of the construction of the chambers is gas tightness. Low oxygen and high carbon dioxide levels are to be maintained to reduce the respiration and transpiration losses of fruits stored in the Controlled Atmosphere (CA) chambers. Gas tightness becomes important to maintain low oxygen levels. This paper presents the first of its kind of results for gas tightness test results of CA chambers in India. The CA chambers are constructed with factory build Poly Urethane Foam (PUF) panels and assembled at the cold/CA storage site. Ribbstyle make paint along with non-woven cloth is used to join the gaps of the insulation panels. Before storing apples in the chambers, gas tightness test is conducted for checking leakages from the walls. As per the international standard for gas tightness, pressure drop from 10 mm of water column to 3 mm of water column is permitted in 30 minutes of time of inflation. Rate of pressure drop is modeled mathematically, and results are presented. Based on the results of this pneumatic test, future work may be taken up to categorize CAS chambers as Ultra low oxygen storage (less than 0.5% O_2), Low oxygen (0.5-2.5% O_2) and High oxygen (2.5 – 15% O_2) storage chambers and are used for relevant apples.

KEYWORDS: Controlled Atmosphere Storage (CAS), Gas Tightness, Elastic Paint, Pneumatic Test, Semi-hermetically Sealed Chamber & Low Oxygen

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Original Article

INTRODUCTION

Controlled Atmosphere Storage (CAS) is a successful technology in storing fresh fruits for long periods compared to cold storage. A cold storage keeps fruits and vegetables at low temperature which retards the respiration rate and thereby delays ripening. Normal cold store walls are constructed with steel panels with insulation sandwiched between the panels. The insulation materials are polyurethane foam (PUF), glass wool, rock wool or Styrofoam, etc.

Controlled atmosphere storage chambers need better insulation with gas tightening. This is due to the requirement of maintaining of low oxygen, high nitrogen and high carbon dioxide within the chamber of fruit storage. A semi-hermetic chamber needs to be constructed for maintaining the low oxygen conditions within the

CAS chamber. This necessitates the proper sealing of all the joints of the insulation panels, doors, inspection window, pipelines supplying nitrogen, oxygen, carbon dioxide scrubber lines, breather bag joints and pipes. When the chamber is connected with these many joints, it is obvious that the storage chamber sealing becomes very important. For this purpose, an elastic paint is used to carefully seal all the joints of the storage chambers. Construction of storage chambers is a major challenge due to its requirements of low oxygen permeability.

This experimental investigation is aimed to study the gas tightening of CAS chambers, pneumatic testing of the chambers before sealing, Rate of pressure drop during pneumatic testing, verifying the gas tightness with respect to the quality standard ISO 6949 and modeling the rate of pressure drop during testing. This data is going to be helpful for future studies on gas tightness of controlled atmosphere storage chamber construction.

LITERATURE OVERVIEW

Utilization of controlled atmosphere storage for longer shelf life of apples of Indian varieties is discussed in detail by Ramesh Babu et al., 2018 [1]. Narasimha Rao et al., 1993, Narasimha Rao et al., 1992 [2-4] have studied the fundamental pre-cooling process of fruits before storage. Sadashive Gowda et al., 1997 [5] has studied the bulk hydraircooling of spherical fruits and numerical modeling has been done.

Bishop (1990) and Bishop (1994) [6-7] has highlighted the necessity of gas tightness for CAS chambers. He also gave the guidelines for test procedure for CAS chambers after construction and before storage. He recommended the necessity of proper maintenance of the chambers, preparation for gas tightness and testing the chambers periodically, typically before the starting of every fruit season. This has to be done before the fruits are stored in the CAS chambers. He also highlighted the importance of specific leakage rate of CAS chambers in the contract between owner and contracting firm making CAS. Yearly need of gas tightness was also specified. A typical leak testing is done by lowering or raising the room pressure and measuring decay rate.

Maximum pressure recommended were 250 Pa (1 inch or 25 mm of water column gauge). A sensitive indicator, either inclined tube manometer or a “magnahelic” indicator can be used for monitoring the pressure decay.

Very critical requirements were given by Bishop, related to checking all doors, hatches, valves, drains and pipes and sealing them to avoid gas leakage. In UK, the practice is to measure time required to verify pressure drop from 20 mm of water gauge to 13 mm. for chambers of oxygen levels of 2.5% and above the minimum time recommended is 7 minutes. For stores with below 2% oxygen, minimum recommended time is 10 minutes. A well constructed store should take 30 minutes to lose the pressure of 7 mm of water column.

ISO 6949 gives clear protocol of gas tightness test. This standard provided the complete requirements for leak proof chambers suitable for fruit and vegetable preservation under low oxygen and high carbon dioxide conditions, i. e. CAS.

Typically, the test is done at 10 mm of water column. The chamber is to be sealed and a pressure of 10 mm is created with an air blower or other device. Once the pressure is built up, the air blower is to be removed and the pressure drop is monitored in the inclined tube manometer. Typically, 100 Pa to 30 Pa drops should take minimum 30 minutes. If the pressure drops within 30 minutes below 30 Pa, it is required to be treated as improper gas tightness.

Several critical technological aspects of CAS for Indian fresh produce are discussed by Ramesh Babu (2014) [8]. The temperature, humidity, gas conditions, nitrogen, oxygen, carbon dioxide scrubbing and other engineering requirements along with machinery design and maintenance are reported.

Donahaye et al., 2001 [9] used negative pressure for gas tightness testing of date fruit storage cube. They have used the pressure decay method suggested by Annis and Van Graver. Monitoring of pressure was done by a transducer. Negative pressure was created by a suction fan. Tests were conducted before loading of dates for storage. 40 to 60 mm of water column pressure (negative) was used as initial pressure. Results were analyzed in terms of half lifetime of pressure decay. This is the only research found in the literature with regard to the pressure decay/gas tightness testing of storage chambers. Their storage cube size is 151 cubic meters.

Several researchers of CAS of apples highlighted the importance of low oxygen storage and benefits for very long-term apple preservation [10-16]. However, their research work is on nutritional aspects and bio-chemical changes along with physical attributes of apple fruits during CAS storage. Technical aspects of agricultural projects and project management are thoroughly discussed by several researchers. Refrigeration and insulation requirements for ripening of mango and banana in controlled environment chambers are thoroughly given by several researchers [17-20]. Vapour tight coatings are made as per the manufacturer's recommendations. [21]

MATERIALS AND METHODS

- **Inclined tube manometer:** An inclined tube manometer (range -30 to +30 mm of water column) is used for the pneumatic testing. The instrument is first fixed to the wall of the chamber with leveling instrument. Water is filled into the manometer to indicate the level to zero first. The procedure prescribed by Bishop is used in our experiments. A pressure drop of 7mm should take up in 30 minutes.
- **Air blower:** An air blower is used to create the pressure required in the controlled atmosphere storage chamber. Once the desired pressure is created the valve connecting the blower to the chamber is sealed before measuring the pressure drop.
- **Controlled atmosphere storage chamber:** The chamber where the pressure testing conducted is of the size of 10 m length, 9 m width and 8 m height. The total volume of the chamber is 720 cubic metres. Doors are sealed using 4mm gaskets attached at the edges between chamber and the door inner side. Door is tightened using mechanical screw jack arrangement on all sides
- **Elastic paint:** Ribbstyle make paint is used for sealing of all joints of the insulation panels in all parts of the 720 m^3 chamber. This will arrest all possible leakages from or into the chamber.
- **Floor sealing:** Entire floor of the chamber was constructed with six-layer flooring. Bottom most floor is the concrete, second layer with PUF slabs of 50 mm thickness of two layers, third layer with concrete with 200-micron plastic liner sheet for moisture and gas barrier, the final layer is done with 5 mm epoxy coating. Overall floor is made with no gas leakage or moisture leakage from or to the chamber.

Figure 1: Inclined Tube Manometer (Scale in mm of Water Column).

Figure 2: Sealing of all Chamber Panel Joints with Ribbstyle Elastic Paint. A Typical Joint Width is 10 cm and Length is 9 meters from Floor to the Top of the Chamber. About 50 such Joints are to be Sealed.

Figure 3: Chamber Inner View of Sealing of C A S Door (Door size: 4.5 m x 5.5 m).

Figure 4: Sealing of Door (Outer view of the Chamber).

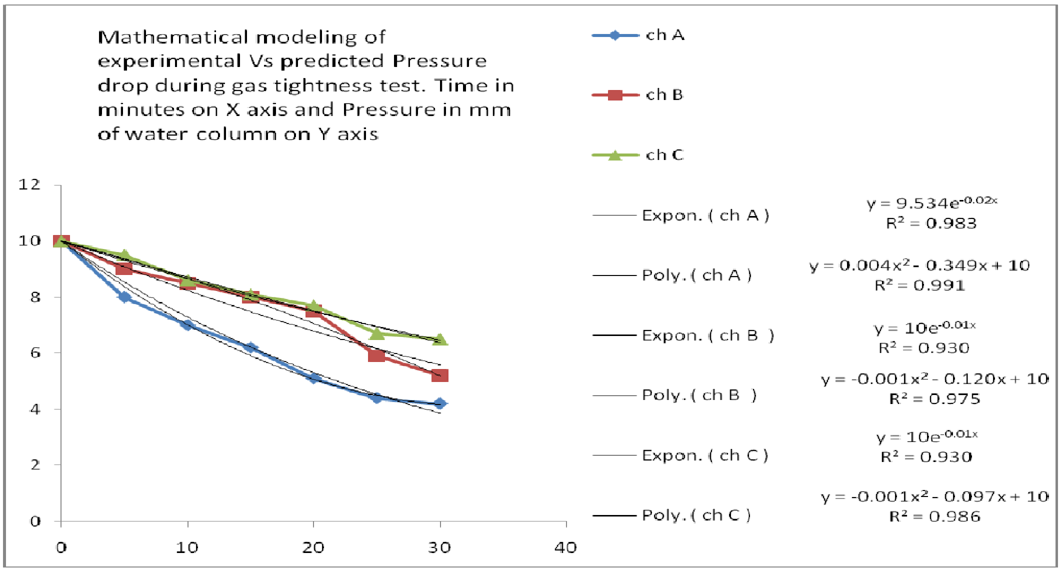

Figure 5: Data Showing the Pressure Drop and Modeling Parameters of Polynomial and Exponential Mathematical Equations.

Table 1: Results of Gas Tightness Test with Calculation on Percent of Pressure Drop up to 30 Minutes (Minimum Time Considered for Calculation is 15 Minutes)

Time (Minutes)	Pressure (mm of Water Column)			% of Pressure Drop		
	ch A	ch B	ch C	ch A	ch B	ch C
0	10	10	10	-	-	-
5	8	9	9.5	-	-	-
10	7	8.5	8.6	-	-	-
15	6.2	8	8.1	38.00	20.00	19.00
20	5.1	7.5	7.7	49.00	25.00	23.00
25	4.4	5.9	6.7	56.00	41.00	33.00
30	4.2	5.2	6.5	58.00	48.00	35.00

RESULTS AND DISCUSSIONS

The pressure testing results are plotted in Figure 5 for three CAS chambers. The inflation of air pressure took about 5 to 6 minutes to reach 10 mm of water column. A precision stopwatch records the time at different pressure levels. The pressure drop data is found to be in the similar trend found by Donahaye et al (2001). The rate of change found to be different compared to their data. This may be due to the chamber volume difference. The chamber under testing of this experiment is of 720 m^3 and they have conducted experiments on the cubical chamber of 151 m^3

The pressure drop results are modeled with two mathematical models: one with exponential model and other one with second order polynomial equation. In all three chambers studies, it is found that polynomial equation fitted best with highest R square values (0.97 to 0.99) compared to exponential model.

The rate of pressure drop is analyzed and presented in Table 1. A new method is proposed to rate the gas tightness of chambers based on the percent of pressure drop to make the data useful for deciding to be suitable for different oxygen level storage of fruits. It is to be mentioned that all the chambers tested pass the minimum requirement of keeping drop below 7 mm of water column up to 30 minutes. The lowest pressure drop found in chamber C with 35% drop and highest percent pressure drop found in chamber A with 58%. Moderate drop is found in chamber B with 48%.

CONCLUSIONS

The pressure drop data of gas tightness is reported. It may be interesting to mention that this is the first report on gas tightness results of controlled atmosphere storage in India. The results are modeled mathematically using two models, viz. exponential and second order polynomial. Satisfactory fit is found between experimental and predicted values with the second order polynomial model with R square values ranging from 0.97 to 0.99. A new method is proposed for utilizing this pressure drop data to make the chambers suitable for three different oxygen level requirements. Based on the results of this pneumatic test, future work may be taken up to categorize CAS chambers as Ultra low oxygen storage (less than 0.5% O_2) and Low oxygen (0.5 – 2.5% O_2) oxygen, high oxygen (2.5 – 15%) and are used for relevant apples. The future work may be conducted to find the precise requirements of high oxygen, low oxygen and ultra low oxygen storage chambers

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AUTHOR'S PROFILE

Dr Ram Deshmukh is Professor and Head of Electrical and Electronics Engineering Department. He has completed his Under graduation at Nagpur University, PhD in the area of Energy Efficient Machines in 2007 from Cardiff University, United Kingdom. He has 12 years of Industrial Experience and 5 years of teaching experience in the UK. He was as Chief Engineer in ATB Laurence Scott, Senior Design Engineer in Brush Electrical Machines Ltd, Electrical Engineer in Corus Construction and Industrial Ltd (TATA Steel UK). He was lecturer in University of Sunderland. He is an international qualified teaching professional with PG Certificate in Higher Education from University of Sunderland. He has achieved many international awards that includes Dennis Hatfield memorial Prize for Best Article in UK Magnetic Society magazine , UKMAG, Business Contribution Award in Corus Steel UK, Excellent contribution as Design Mentor in Smart India Hackathon- Hardware Edition, Kharagpur, India.

He received award from Steel Authority of India Ltd for Solving their Industry Problem during his undergraduate Studies. He also received Best Presentation Award in Magnetism and Magnetic Conference, San Diego, USA. He has published technical research papers in reputed International Journals viz. IEEE Transactions of Magnetic Material, Journal of Applied Physics, Journal of Magnetism and Magnetic Material. He is the Director in a company named "Real Pandu", a fruit ripening company.

D. Ramesh Babu has over 24 years of experience in manufacturing, research, maintenance, consultancy and project management related to Refrigeration, food processing and controlled atmosphere. He was graduated in Mechanical Engineering from JNTU College of Engineering, Hyderabad in the year 2000 and obtained MBA in production and operations management from MDU, Rohtak. He also obtained his MTech in Advanced Manufacturing from JNTU, Hyderabad. He has got expertise in refrigeration, fruit preservation and food processing. He is presently working as

Assistant Professor in Mechanical Engineering at S R Engineering college, Warangal. He has four years of experience in refrigeration equipment manufacturing at Voltas Limited, seven years of experience in fruit preservation at Defense food research laboratory, DRDO-Mysore and worked for eight years at cold chain project of CONCOR before joining teaching.

He is a recipient of DRDO cash award in the year 2003. He was nominated by CONCOR for eight days visit to ISRAEL as part of cold chain project for preservation of apples in the year 2011. He has published 4 research papers in SCI indexed journal and 9 papers in SCOPUS indexed journals and 6 in ICI indexed journals. He also presented numerous papers at various International and national conferences. His paper got best paper award by the TJPRC for the paper on "The Design of Refrigeration, Thermal Insulation and an Equipment for Healthy Ripening of Mango and Banana Without Using Harmful Chemicals." published in IJMPERD. He has filed one patent in the year 2019. He is currently pursuing his PhD in Mech. Eng. at KLEF, Vijayawada. He is a life member of Condition Monitoring Society of India and Graduate member of Institute of Engineers (India).

Dr K V Narasimha Rao is a senior Professor with 27 years experience in Academic, Consultancy and Industry and has been working with KLEF (Deemed to be University) since 2 September 2016. Dr Narasimha Rao was graduated in Mechanical Engineering from Regional Engineering College, Warangal in 1986 and went on to obtain master's and Doctoral degrees from the Indian Institute of Science, Bangalore during 1990 and 1995 respectively in the field of Thermal Engineering. He worked for seven years (1995-2002) as Research Associate and Fellow, Industrial Energy Group at Tata Energy Research Institute (Teri), Southern Regional Centre, Bangalore before moving into Academics, Research and Administration during 2002. Prior to joining KLEF, he worked at few Engineering Colleges as Principal/Director/Dean. Dr Rao has published 28 scientific papers , 3 in SCI Listed Journals, 24 Scopus indexed Journals and Chapter 10 in Recent Advances in Material Sciences, Lecture Notes on Multidisciplinary Industrial Engineering) and numerous technical reports for various National/International Agencies. He has filed 14 patents (five published).